DEVELOPING ROBUST EVACUATION INSTRUCTIONS WITHIN AN INTELLIGENT EVACUATION, RESCUE AND RECOVERY SYSTEM

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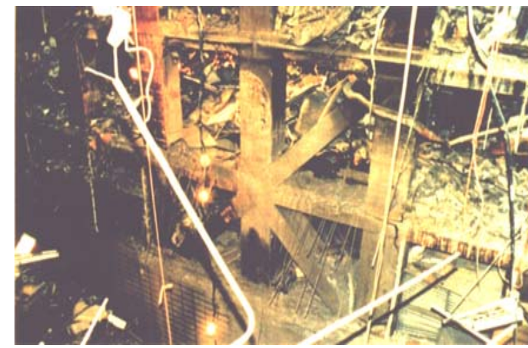
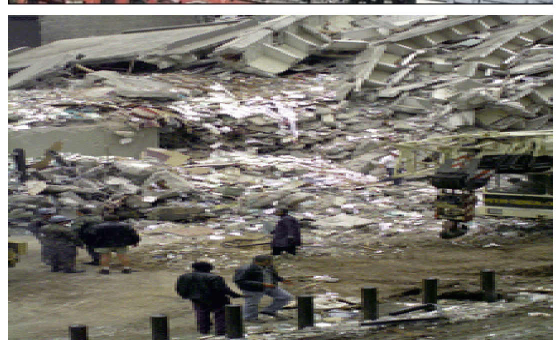
Motivation

Improving evacuation, rescue, and recovery (ERR) related response in large buildings.





Intelligent evacuation, rescue and recovery

Post-attack ERR activities can significantly benefit from computer-based modeling and decision support tools.

Some key issues:

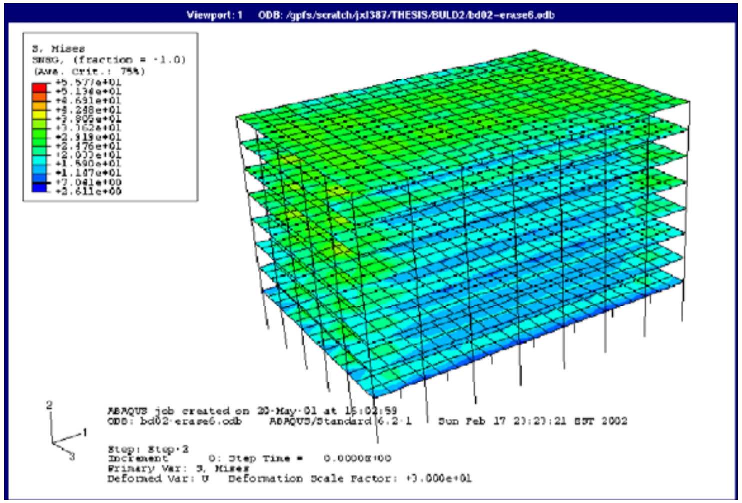
Damage assessment	Real-time assessment on continuous basis of extent of blast damage to building. Full-scale BDA & TVA tool.
Evacuation	Emergency preparedness planning and on-line dynamically updated instructions to evacuees in response to evolving conditions.
Rescue	Dynamically updated instructions to rescue workers (paths to trapped evacuees & in seeking safe egress/refuge).
Recovery	Updated mitigation actions, optimal demolition/ construction actions, restoring functionality of building.

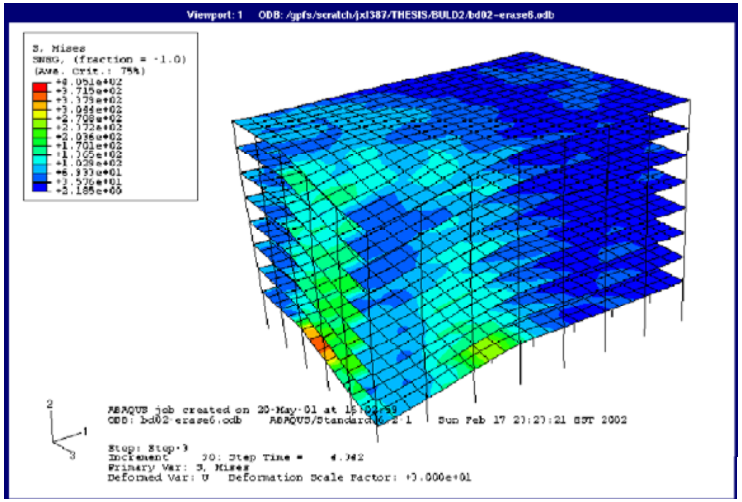
Automated & electronically integrated system

Functionality stems from electronic integration of two components.

Real-time damage assessment (BDA/TVA) tool

- Enabled through the use of sensor technology.
- Used to track damage and hazard evolution (including fire and smoke) and assess in real-time current and predicted operational capacity of building structures and circulation systems.





Automated & electronically integrated system

Functionality stems from electronic integration of two components.

On-line ERR-related optimization techniques

Dynamically update instructions in response to evolving conditions as provided by damage assessment tool.

Both components consider real-time & predicted future conditions (e.g. evolution of damage and failure risk).

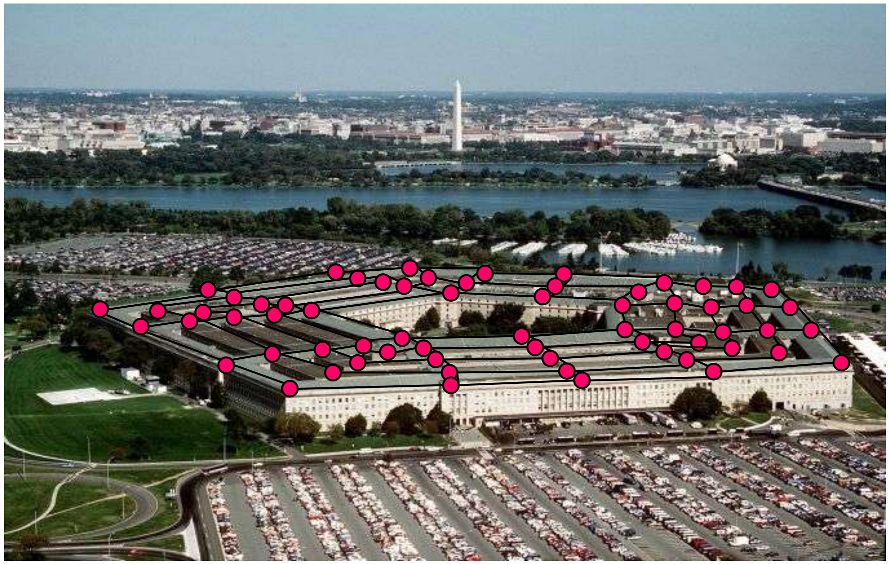
Network representation

Circulation systems represented by a network of nodes & arcs.

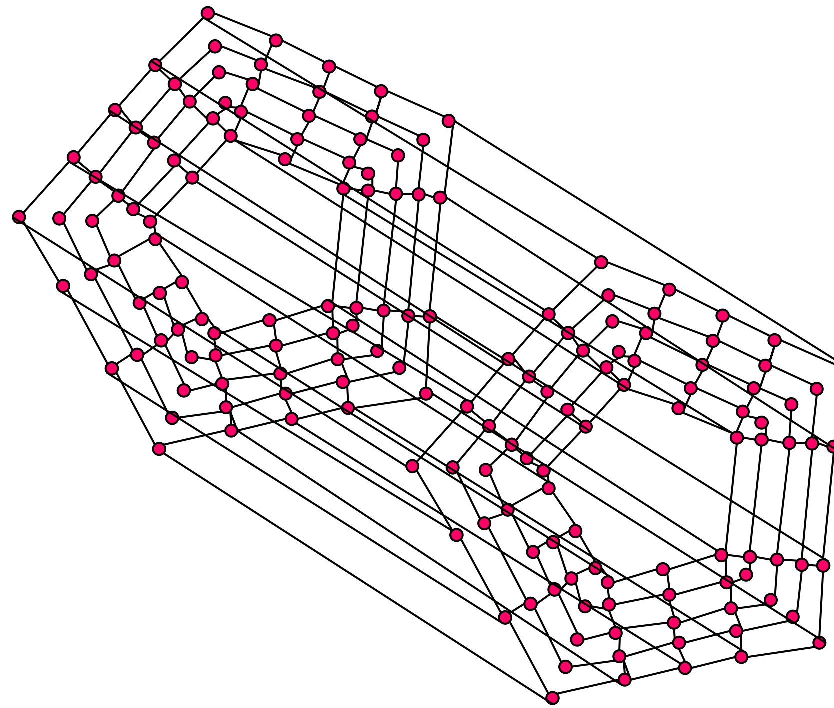
Nodes	Locations (offices, meeting rooms, lobbies, corridor intersections, exits & safe havens).
Source nodes	Location of people when evacuation begins.
Sink nodes	Location of exits (including safe havens).
Arcs	Passages connecting locations (e.g. stairwells, ramps, corridors, doorways & elevator shafts).
Arc weights	Arc traversal times (e.g. time for each person to traverse the arc).
Arc capacities	Number of people who can pass through the associated passageway per unit of time.

Illustrative network

Simplified network representation of the Pentagon.



Simplified network representation of single story

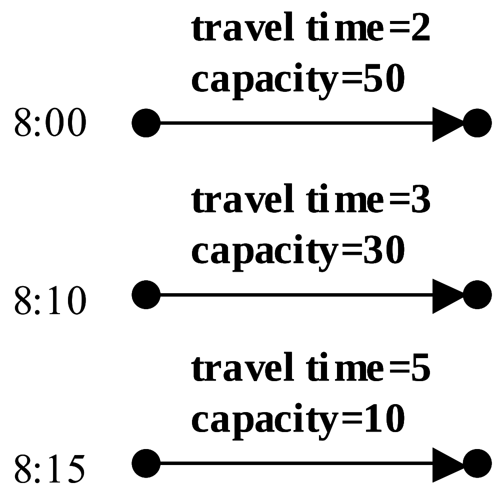


Connecting two stories

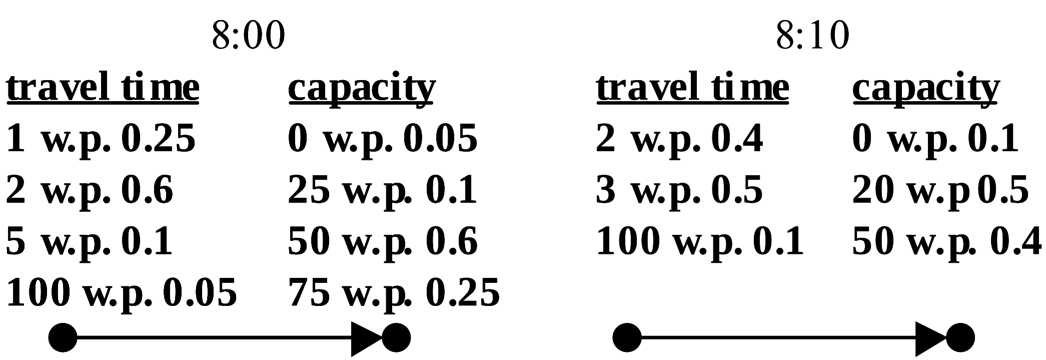
The network representation is exploited in developing the optimization techniques.

Dynamic and probabilistic characteristics

Arc capacities may decrease over time (as fire spreads…), traversal times may increase as conditions worsen.



Time-varying arc attributes



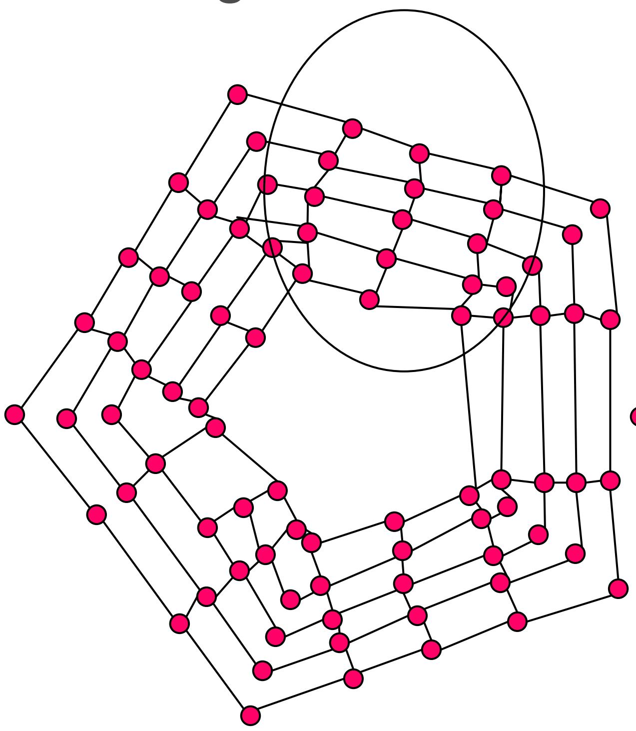
Time-varying and probabilistic arc attributes

The Pentagon: September 11, 2001

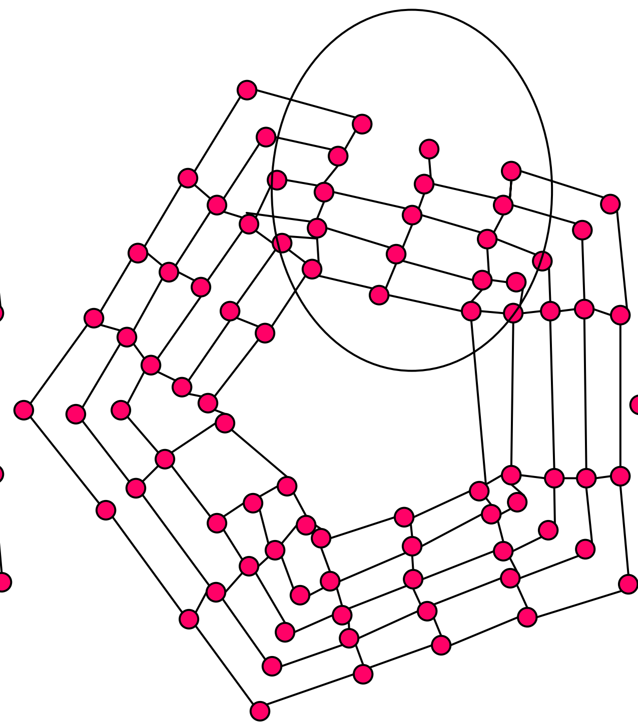
Hypothetical scenario for the Pentagon

Conditions worsen in short period of time.

Damage to the building →changes in connectivity & arc attributes

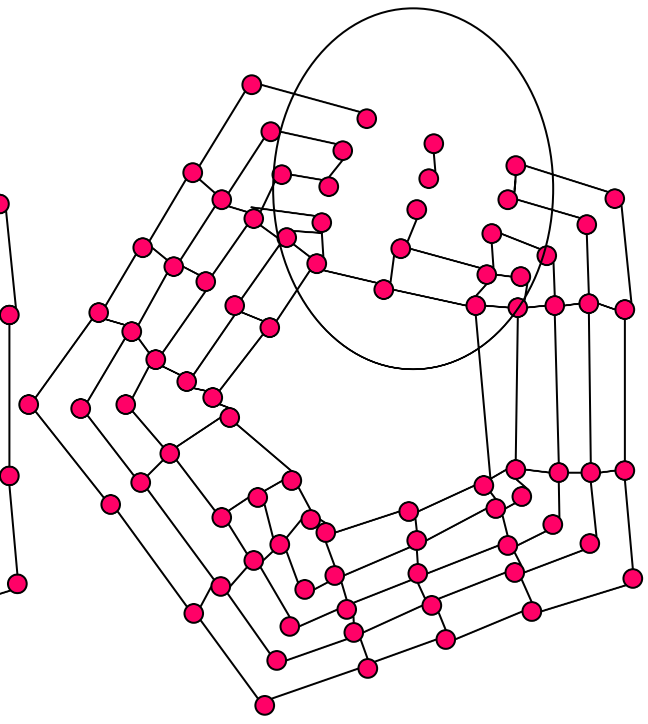


Before attack



After attack

Stage one



After attack

Stage two

Critical issues in providing instructions

Explicitly consider damage evolution and predictions of future remaining capacities.

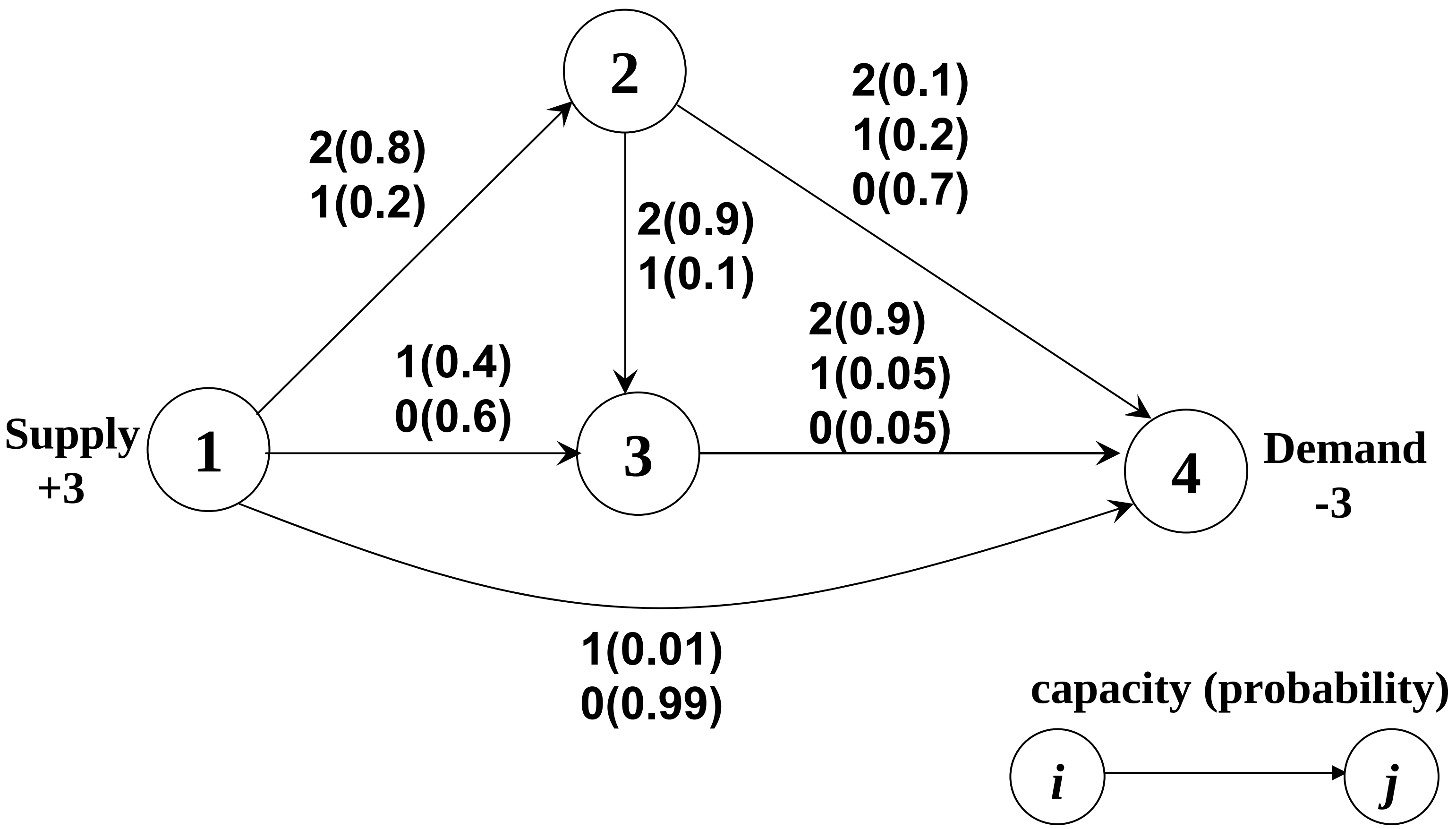
Must be careful not to route an evacuee to an arc that would have a high likelihood of failing by the time he or she arrives at that location.

In emergency evacuations

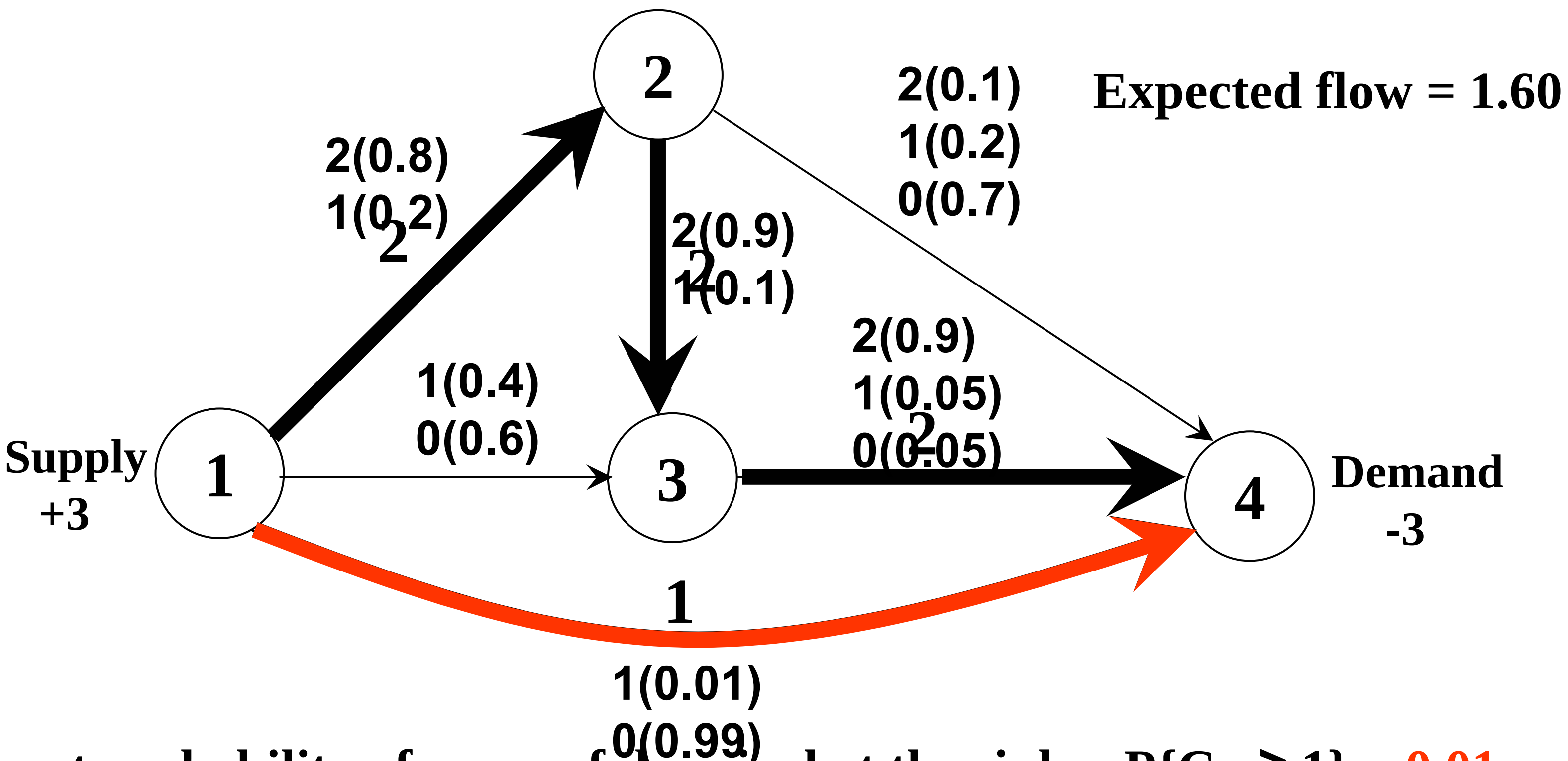
- dangers strengthen and spread over time.
- successful egress may be inhibited by partial or complete failure of key escape paths.
- dynamic and uncertain nature of capacities inherent in such circumstances.
- fairness to all evacuees is critical.

Expected flow

The maximum expected flow paths may results in very risky paths for some.

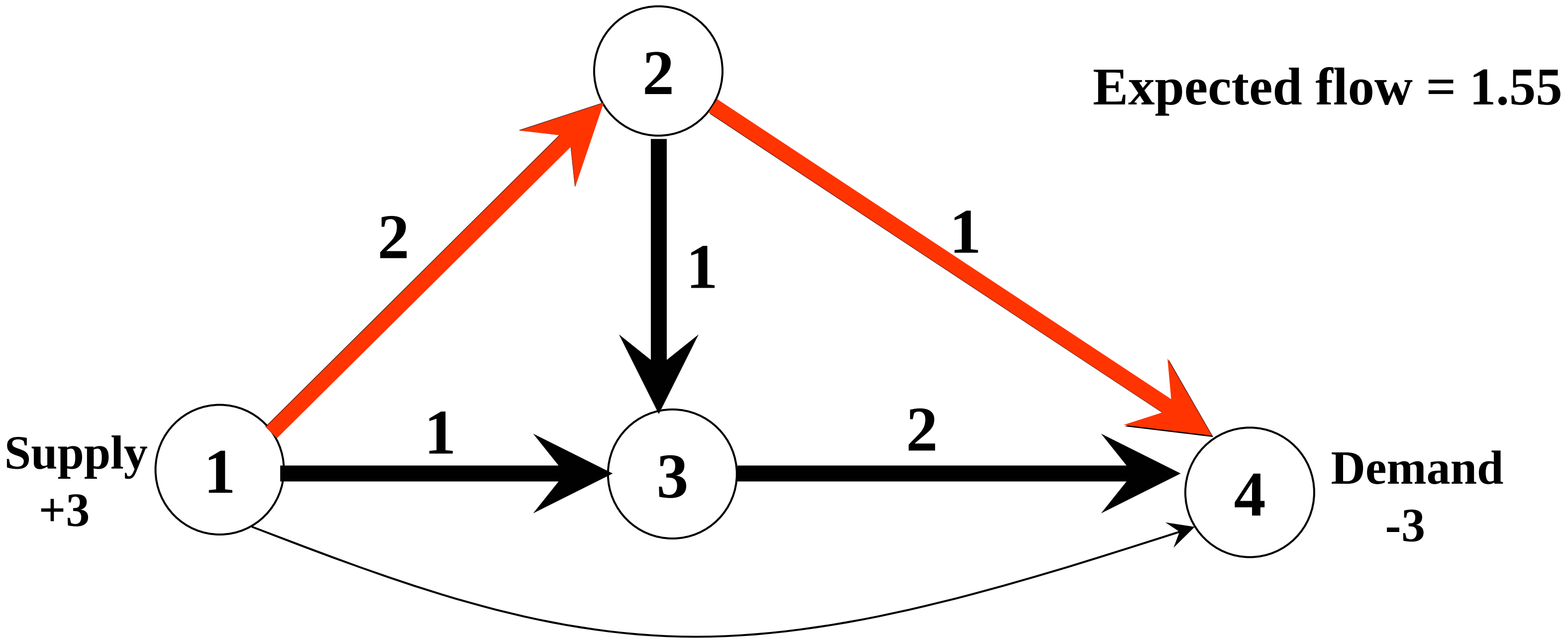


Solution I: maximum expected flow



Least probability of successful arrival at the sink = $P\{C_{14} \geq 1\}$ = 0.01

Solution II



Least probability of successful arrival at the sink
= $P\{C_{12} \geq 2\} \cdot P\{C_{24} \geq 1\}$ = 0.24

One Objective

In one of the algorithms we developed, we seek optimal evacuation instructions that prevent routing any evacuee on a path with a high likelihood of failure.

Consider real-world evacuation conditions

- dynamic capacitated network
- time-dependent arc traversal times
- stochastic, time-dependent arc capacities
- evacuees moving over time
- required waiting not allowed

SEscape (Safest Escape) Problem

Determine the set of path flows with the maximum least probability of successful arrival at the sink in dynamic networks with time-varying travel times and stochastic, time-varying capacities

$$\text{Max } \Big[\min_{\sigma \in \Omega} \prod_{((i,j),t) \in \sigma} \mathrm{P}\{c_{ij}(t) \geq x_{ij}(t)\} \Big],$$

$$\sum_{j \in \Gamma^{+}(i)} x_{ij}(t) - \sum_{j \in \Gamma^{-}(i)} \sum_{\{t' | t' + \tau_{ji}(t') = t\}} x_{ij}(t') = b_i(t), \ \forall i \in \mathcal{V}, t \in \{0, \ldots, T\},$$

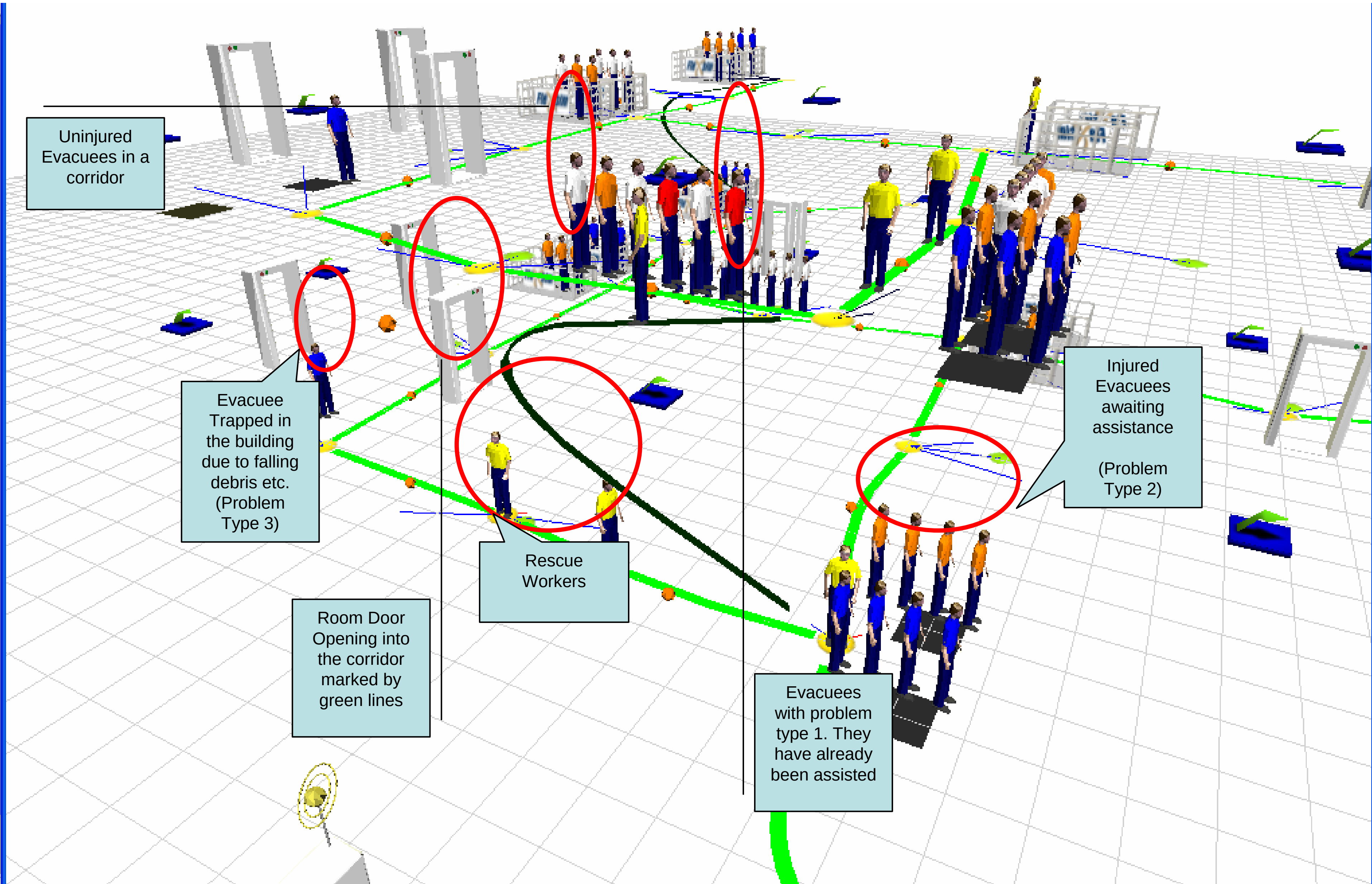
$$0 \leq x_{ij}(t) \leq \max_{z} c_{ij}^{z}(t), \qquad \forall (i,j) \in \mathcal{A}, t \in \{0, \ldots, T\}.$$

where Ω is the set of all possible paths from source to sink

General notes on the SEscape algorithm

- **Extension of TDQFP algorithm** of Miller-Hooks and Stock Patterson (2004).
- **Employs a probabilistic, time-dependent (PTD) residual network** with arc weight values that are related to the probability that the capacity of arc (i,j) at time t is not less than n.
- **Relies on the MPP (maximum probability path) algorithm** to find paths for shipping flow.
- **Probability that each unit will succeed in traversing each arc can be readily obtained** through the special structure of the PTD residual network.

Simulation as a Test-Bed and IERR Prototype



Technologies

On-line instructions facilitated by use of technologies.

Providing path-finding assistance to evacuees

- Changeable message signs
- Photo luminescent signage
- Voice evacuation systems
- RFID (provides location)

Allocating tasks to rescue workers

- Two-way audio-visual devices

Rescue worker location & calls for assistance

- Emergency transponders
- RFID (provides location)

Probe data

- Mobile sensors worn by evacuees/rescue workers

System benefits

- Supports
  - real-time damage assessment
  - target vulnerability assessment
  - emergency preparedness planning
  - on-line assistance with ERR
  - platform for training
- Faster, more efficient evacuation in event of various emergencies

System benefits

- Enables processes with reduced labor intensity, increased consistency, increased speed of response.
- Enables effective and objective exchange of information and rapid planning and execution.
- Meets complicated variable emergency conditions with lower resource requirements.
- Permits recovery efforts to begin quickly.
- Explicitly considers inherent stochastic and dynamic nature of future conditions.
- Employs information on current and near-term performance of building and its circulation systems.

Enables <u>robust</u> and rapid decision-making.

What's next?

- Modeling human behavior in the simulation model.
- Development of the conceptual framework for human-centered "optimization" algorithms and development of the algorithms themselves.
- Multi-objective models and solution approaches.
- Rethinking risk: People have different preferences and aversions toward risk.